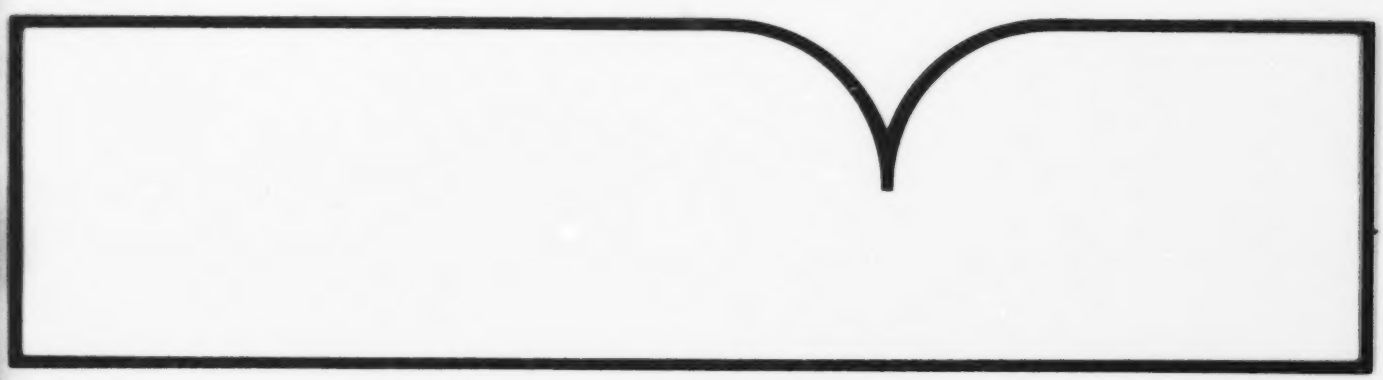
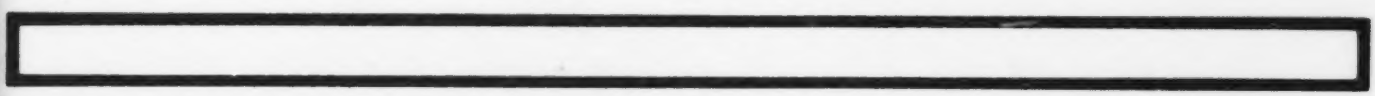
PB88-132907

Methods for Estimating On-Site Ambient Air Concentrations at Disposal Sites

(U.S.) Environmental Protection Agency
Washington, DC

23 Feb 87





U.S. Department of Commerce
National Technical Information Service
NTIS

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO.	2.	3. PB88-132907
EPA/600/J-87/109		

4. TITLE AND SUBTITLE	5. REPORT DATE
Methods for Estimating On-Site Ambient Air Concentrations at Disposal Sites (Journal Version)	November 1987
	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S)	8. PERFORMING ORGANIZATION REPORT NO.
Seong T. Hwang	
9. PERFORMING ORGANIZATION NAME AND ADDRESS	10. PROGRAM ELEMENT NO.
Same as (12)	11. CONTRACT/GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS	13. TYPE OF REPORT AND PERIOD COVERED
Office of Health & Environmental Assessment Exposure Assessment Group (RD-689) U.S. Environmental Protection Agency Washington, D.C. 20460	Journal Article
	14. SPONSORING AGENCY CODE EPA/600/21

15. SUPPLEMENTARY NOTES

Nuclear and Chemical Waste Management, 7:95-98, June 1987

16. ABSTRACT

Currently, Gaussian type dispersion modeling and point source approximation are combined to estimate the ambient air concentrations of pollutants dispersed downwind of an areawide emission source, using the approach of virtual point source approximation. This Gaussian dispersion modeling becomes less accurate as the receptor comes closer to the source, and becomes inapplicable for the estimation of on-site ambient air concentrations at disposal sites. Partial differential equations are solved with appropriate boundary conditions for use in estimating the on-site concentrations in the ambient air impacted by emissions from an area source such as land disposal sites. Two variations of solution techniques are presented, and their predictions are compared.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field Group

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS (This Report)	21. NO. OF PAGES
Release to Public	Unclassified	7
	20. SECURITY CLASS (This page)	22. PRICE
	Unclassified	$29.95/$6.95 MF

EPA Form 2220-1 (9-73)

REPRODUCED BY
U.S. DEPARTMENT OF COMMERCE
NATIONAL TECHNICAL
INFORMATION SERVICE
SPRINGFIELD, VA. 22161

EPA/600/J-87/109
JOURNAL ARTICLE

NUCLEAR AND CHEMICAL WASTE MANAGEMENT, Vol. 7, pp. 95–98, 1987
Printed in the USA. All rights reserved.

0191-815X/87 $3.00 + .00

METHODS FOR ESTIMATING ON-SITE AMBIENT AIR CONCENTRATIONS AT DISPOSAL SITES

S. T. Hwang

Exposure Assessment Group (RD-689), U.S. Environmental Protection Agency, Washington, D.C. 20460, U.S.A.

ABSTRACT. Currently, Gaussian type dispersion modeling and point source approximation are combined to estimate the ambient air concentrations of pollutants dispersed downwind of an areawide emission source, using the approach of virtual point source approximation. This Gaussian dispersion modeling becomes less accurate as the receptor comes closer to the source, and becomes inapplicable for the estimation of on-site ambient air concentrations at disposal sites. Partial differential equations are solved with appropriate boundary conditions for use in estimating the on-site concentrations in the ambient air impacted by emissions from an area source such as land disposal sites. Two variations of solution techniques are presented, and their predictions are compared.

INTRODUCTION

Several environmental regulations promulgated pursuant to the Congressional mandates require that hazardous waste sites contaminated with volatile or semivolatile toxic waste be evaluated for potential human exposure associated with vapor inhalation. After or before cleanup of the contaminated site, the on-site ambient air concentrations affecting the population living or carrying out constant activities in the area are normally higher than downwind concentrations. Hence, estimating the ambient air concentrations on-site of an areawide contaminated source becomes an important part of the overall exposure assessment, and particularly becomes important in accurately assessing risks associated with the vapor inhalation pathway. Despite this importance, the methods for estimating ambient air concentrations on the site where emissions occur are virtually nonexistent.

Gaussian dispersion modeling, originally developed for estimating the ambient air concentration of contaminants dispersed from point-source emissions, is extended in its application to dispersion of area source emissions to estimate the ambient air concentrations of pollutants dispersed and transported downwind of an area emission source. This approach is based on combining the Gaussian dispersion modeling and point source approximation for an area source, and is referred to as virtual point source approximation. A good example of this approach is EPA's Industrial Source Complex Model (1). Virtual point source approximation assumes that [1] there is a virtual point source upwind of the area source, the plume of which will approximate the plume of emissions from the area source when the emissions reach the area source, and [2] the concentration at a point within a sector of 16 wind directions can be represented by the average concentration over the arc of the sector.

This virtual point is calculated from the consideration of the geometric relationship between the facility size and the distance to the facility. The limitation of the virtual source approximation is that the distance from facility center to receptor should be the greater of [1] the distance from facility center to property line, and [2] 100 meters (2). The vertical standard deviation σ_z is approximated by assuming that the dispersion distance is from facility center to receptor.

This Gaussian modeling becomes less acurate as the receptor comes closer to the source, and becomes inapplicable for the estimation of on-site ambient concentrations. At present there are no dispersion models that have been reported in the literature for use in predicting the on-site ambient air concentrations on the site from which emissions occur over a nonpoint area. Hwang and Thibodeaux (3) developed a mathematical relationship for pre-

RECEIVED 22 OCTOBER 1986; ACCEPTED 23 FEBRUARY 1987.

dicting the emission rate from the on-site measurements of temperature and velocity profiles, and the net ambient concentration. This relationship can in turn be used to estimate the on-site ambient air concentrations, once the temperature and velocity measurements are available. But such measurements may be impractical for application to dispersion modeling problems.

This paper will present methods for estimating the on-site ambient air concentrations. Models are developed using two different approaches. One approach considers an infinitesimal element of the area source as a point source, and sums up all the contributions from each point source over the entire area source. This method requires a double integration of the Gaussian-type dispersion modeling over the emission area extending in x-y directions. The second approach involves a partial differential equation describing the micrometeorological material balance around an air mass. These model results will be compared to each other and also with the results of the box-model approach developed for an approximate assessment (4).

MODEL DEVELOPMENT FOR ONSITE AMBIENT AIR CONCENTRATIONS

First, Gaussian dispersion modeling for point source emissions with be utilized. For emissions occurring from a point source at ground level, the ambient air concentrations at any point downwind is

$$C = \frac{Q}{\pi \bar{u} \sigma_y \sigma_z} e^{-\frac{1}{2}\left(\frac{y^2}{\sigma_y^2} + \frac{z^2}{\sigma_z^2}\right)^2} \quad (1)$$

where

C = ambient air concentration (g/cm^3),
$\bar{u}$ = wind speed (cm/s),
Q = total emission rate (g/s), and
σ_y, σ_z = standard deviations in the lateral (y) and vertical (z) directions, respectively (cm) (5).

Among the assumptions made in deriving Eq. 1 are that diffusion in the downwind x-direction is negligible compared to the transport of pollutant due to the wind, that some average wind speed is possible although the wind speed varies logarithmically with respect to height, and that plume dispersion is under steady-state conditions.

Although Eq. 1 applies only for point source emissions, the area source can be thought of as consisting of a series of point sources bounded by its dimensions. If we let the emission rate per unit area of an area source be q g/cm^2·s, the contribution to the ambient air quality at the receptor by each point source $q\ dx'dy'$ located at x' and y' can be summed to get the total impact on the concentration at that receptor. The use of the standard method for changing the coordinates for a point and integrating the differential change in air concentrations, dC, over the contaminated area, will provide a net contribution to the receptor from all of the point sources on the site. The solution to this integration can be easily obtained as

$$C = \frac{q \cdot a}{\sqrt{2\pi}\bar{u}\sigma_z} e^{-\frac{1}{2}\left(\frac{z}{\sigma_z}\right)^2} \left[\operatorname{erf}\left(\frac{y + \frac{b}{2}}{\sqrt{2}\sigma_y}\right) - \operatorname{erf}\left(\frac{y - \frac{b}{2}}{\sqrt{2}\sigma_y}\right)\right] \quad (2)$$

where a, b = dimension of the contaminated site in the x and y directions (parallel and perpendicular to the wind), respectively.

In many assessment evaluations, the population exposed to the worst on-site ambient air concentrations is of concern. These concentrations occur along the center line of the contaminated site. For these concentrations, Eq. 2 simplifies to

$$C = \sqrt{\frac{2}{\pi}} \frac{q \cdot a}{\bar{u}\sigma_z} e^{-\frac{1}{2}\left(\frac{z}{\sigma_z}\right)^2} \operatorname{erf}\left(\frac{b}{2\sqrt{2}\sigma_y}\right) \quad (3)$$

Equation 3 applies to the one-site center line ambient air concentration at a height z from an area source at ground level.

In the second approach, the dispersion model for estimating the on-site ambient air concentrations is obtained by solving partial differential equations with appropriate boundary conditions. For steady dispersion phenomena, atmospheric dispersion can be expressed by

$$\bar{u}\frac{\partial C}{\partial x} = \frac{\partial}{\partial x}\left(D_x \frac{\partial C}{\partial x}\right) + \frac{\partial}{\partial y}\left(D_y \frac{\partial C}{\partial y}\right) + \frac{\partial}{\partial z}\left(D_z \frac{\partial C}{\partial z}\right) \quad (4)$$

where

D_x, D_y, D_z are the diffusion coefficients in x, y, and z directions, respectively,
C is the one-site ambient air concentration, and
$\bar{u}$ is the average wind speed (5).

Under the turbulent atmospheric conditions which represent normal situations in the atmosphere (3), Eq. 4 can be simplified to

$$\bar{u}\frac{\partial C}{\partial x} = D_z\frac{\partial^2 C}{\partial z^2} \quad (5)$$

Boundary conditions in solving Eq. 4 can be set by letting $t = x/\bar{u}$, or

$$\frac{\partial C}{\partial t} = D_z\frac{\partial^2 C}{\partial z^2} \quad (6)$$

Physically, the term t represents the time that a contaminant took in traveling a distance x along with the winds at an average speed of $\bar{u}$. Equation 6 can be solved by the following boundary conditions:

B. C. 1 $C = 0$ at any t, $z = \infty$ (7)

B. C. 2 $C = 0$, at $t = 0$, any z (8)

B. C. 3 $D_z\frac{\partial C}{\partial z} = q$ at any t, $z = 0$ (9)

B. C. 1 states that at the infinite vertical height far removed from the source, the concentration of the contaminant attributable to the area source is negligible; B. C. 2 states that at the leading edge of the area source, there is no contribution to the ambient air contaminants by the contaminated area source; and B. C. 3 states that the emissions at the soil-air interface occur according to Fick's law of diffusion. The expression for the emission rate q can be estimated from the air emission release rate models for contaminated soil or water bodies. The emission rate can be uniform steady-state or time-varying.

It is easy to solve Eq. 6 with the given boundary conditions. The solution can be modified by substituting the standard deviation σ_z in place of D_z, using the relationship:

$$D_z = \sigma_z^2\,\bar{u}/2\,x$$

The modified solution takes the form of

$$C = \sqrt{2\pi}\frac{qx}{\sigma_z\bar{u}}\left[1 - \text{erf}\left(\frac{z}{\sqrt{2}\sigma_z}\right)\right] \quad (10)$$

The rigorous solution of Eq. 6 must consider the logarithmic change of wind speed with respect to height. For ease of integration, the solution given is obtained based on an average wind speed $\bar{u}$ at the receptor height. No closed-form solution is available if the logarithmic variation is to be incorporated in the solution.

There is a report presenting the method of estimating the on-site ambient air concentration based on a box-model approach (4). This model was intended to provide a rough estimate of the concentration using the data on wind speed, width of the site, and average height considered appropriate for occurrence of reasonable mixing. This model is very simple in that it does not account for lateral or vertical dispersion. The equation is shown as

$$C = \frac{Q}{\text{LS}\cdot\bar{u}\cdot\text{MH}} \quad (11)$$

where

LS = width of the contaminated site perpendicular to the direction of winds, and

MH = average mixing height within which mixing occurs to impact the height of receptor.

Validation of these three types of model for the on-site ambient air concentrations will require extensive experimental data. Although ambient air data taken at hazardous waste sites are often available for volatile organics in the literature, validation cannot be attempted without appropriate site-specific information, including emission data, data on the extent of contamination, and meteorological data. However, these three models can be compared numerically, and also critical variables which need to be experimentally evaluated will be discussed.

COMPARISON OF MODEL RESULTS

Lack of experimental data does not allow comparison of model predictions with actual data. However, the results of the models derived from the three separate approaches are compared under a set of assumed conditions. These results are shown in Table 1. The size of the area for comparison is a 1/2-acre (2,000 m²) site, considered to be square,

TABLE 1
Comparison of Model Results

	On-site ambient air concentration (g/cm³)
Gaussian area source	6.3×10^{-14}
Area source under turbulent conditions	6.9×10^{-14}
Box model	1.6×10^{-13}

Data: Size of contaminated site = 1/2 acre square (45 × 45 m).
σ_y = 6.5 m.
σ_z = 3.6 m.
$\bar{u}$ = arithmetic average 135 cm/s from ground to z = 2 m.
$q = 10^{-13}$ g/cm²·s.

emitting a contaminant at a uniform rate per unit area of 10^{-12} g/cm^2 s. For time-changing emissions, it would be most convenient to use the time-averaged emission rate in estimating the average ambient air concentration over an exposure period. The time-dependent emission rate can also be used for estimating the ambient air concentration at any time.

The comparison indicates that the results of the Gaussian area source model (Eq. 3) and the area source model under turbulent conditions (Eq. 10) are quite comparable under the assumed conditions. The values for the standard deviations are obtained by extrapolating the literature values to the applicable receptor distance (6). On the other hand, the box model result is larger than the results of the other two models in concentration values by about a factor of 2. This comparison is for model results only. The accuracy of these predictions would not be known until actual experimental data become available, and proper correlations are developed.

DISCUSSION

Critical elements in the use of the models derived in this paper are uncertainties associated with the values for the standard deviations. Although the example comparison shown in Table 1 uses the values for the standard deviations by extrapolating the literature values corresponding to the Class *C* stability, the validity of this extrapolation cannot be certain without experimental data. As far as the on-site contaminant is concerned, it did not travel a great distance before reaching the receptor height. Hence, the plume spread would not have been much affected by different stability classes at such a short time of travel. The question on which stability class correlations would represent, if it does, the actual conditions for on-site concentration is an open one in the absence of some supporting data.

EPA, under cooperative agreements with a research institution, is currently in the process of collecting ambient air data from an area source operated under controlled experimental conditions. The set-up consists of perforated pipes laid out evenly over a rectangular area to simulate area source emissions. Emission rates and meteorological conditions are carefully monitored as well as the size of the structure and other pertinent parameters. This data base should be an important source for validating on-site air dispersion modeling. A similar statement can be made with respect to validating the Gaussian dispersion modeling that predicts the off-site ambient air concentrations from an area source.

REFERENCES

1. U.S. Environmental Protection Agency, Industrial source complex (ISC) dispersion model user's guide, Vol. 1. EPA-450/4-79-030, Prepared by H. E. Cramer Co., Inc. U.S. Environmental Protection Agency, Washington, D.C. (1979).
2. U.S. Environmental Protection Agency, Evaluation guidelines for toxic air emissions from land disposal facilities. Office of Solid Waste, Washington, D.C. (1981).
3. S. T. Hwang and L. J. Thibodeaux, Measuring volatile chemical emission rates from large waste disposal facilities, *Env. Prog.* **2**: 82, (1983).
4. U.S. Environmental Protection Agency, Development of advisory levels for polychlorinated biphenyls (PCBs) cleanup. PB-86-232-774/AS National Technical Information Service, Springfield, VA (1986).
5. K. Wark and C. F. Warner, *Air Pollution: Its Origin and Control*, 2nd ed. Harper and Row, New York, NY (1981).

NOTICE

This document has been reviewed in accordance with U.S. Environmental Protection Agency policy and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

This article documents research that was conducted under the auspices of the U.S. Environmental Protection Agency (USEPA). As an arm of the government, the USEPA has a paid up, non-exclusive, irrevocable, worldwide license to reproduce, prepare derivative works, and distribute to the public all of the material contained herein, and to grant others acting on its behalf the right to do so. The USEPA grants to the National Technical Information Service, Department of Commerce, the right to act as its agent in the distribution of this material.